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Vehicle Location Systems

VEHICLE LOCATION SYSTEMS

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VEHICLE LOCATION SYSTEMS

In order to assess the representativeness of emissions-related driving data from an instrumented vehicle, it is necessary to characterize the locations and, specifically, the road types, where data are collected. In previous, limited term studies[1]*, this has been accomplished through manual data entry in real time by an onboard observer or through review of videotapes after data collection. Both of these approaches are relatively labor intensive and prone to human error. To increase the efficiency and accuracy of specifying vehicle location, various automated vehicle location systems have been investigated.

Based on the survey, the principal competing systems, in terms of coverage, reliability, accuracy and cost, were GPS-based systems and Teletrac. Accuracy is comparable for both systems unless differential GPS is used (at a higher cost), or selective availability is turned off; in either of these cases, GPS offers somewhat greater position accuracy than Teletrac. Teletrac, however, provides both street names and locations, whereas most GPS-based systems would have to be supplemented with a geographical information system. In order to further define its needs and test the capabilities of a commercial vehicle location system, Sierra recommends that ARB arrange to use Teletrac, on a trial basis if possible. Concurrent with this, ARB may want to continue exploring the potential for obtaining alternative systems either as demonstrations by vendors or as a result of functional systems that may by in surplus.

Design Objectives

At a minimum, a vehicle location system to be used for monitoring the travel of on-road vehicles should meet the following criteria:

- provide geographic information sufficient to identify, at any time during the period of data collection, what road is being driven;

- provide for non-labor intensive relative ease of use, with automatic data logging and/or direct linkage to an on-board data logging system in ARB's instrumented Chevrolet Lumina[2]; and

- be available at a reasonable cost (must be more cost-effective than manual data entry).

Additional features that would enhance the utility of the system include:

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*Superscripts denote references listed at end of text.

- the ability to provide not only geographic coordinates but also road names and nearby road locations, so the vehicle's route may be conveniently located after the drive;

- frequent updating of vehicle location such that not only could the roadway be identified but also the exact location of changes in driving behavior that may be observed in datasets;

- the ability to provide not only latitude and longitude, but also altitude or, alternatively, vehicle attitude, in order to infer road grade and its potential effect on engine power demand and emissions; and

- minimum attention demanded by the driver or observer to operate and maintain the system.

The statement of work for this task[3] identified a minimum of three potential approaches that would be investigated for possible use in vehicle location in ARB's Chevrolet Lumina: Global Positioning Systems (GPS), LORAN and dead reckoning. The remainder of this analysis describes these three systems and a closely related fourth type of system which, it is concluded, offers the greatest promise for meeting or exceeding the design objectives outlined above.

Global Positioning Systems

The first modern navigation systems, Decca in the United Kingdom and northern Europe and LORAN in the U.S., were developed in the 1940's[4]. Both rely on a mobile receiver that detects signals from at least three land-based transmitters and uses differences in the signals to infer position. These early systems (LORAN has been greatly improved since) had serious limitations in coverage, applicability or adaptability to different platforms[5].

In 1957, the U.S. Navy started a radio location-based system called Omega which overcame the range limitations of earlier systems, providing accuracy of 2-4 nautical miles for locations anywhere on earth[6]. To further improve accuracy of nautical navigation, the Navy, in 1964, launched a series of relatively low altitude satellites that could be used intermittently to provide position information. While limited in its coverage, the U.S. Navy's Transit system demonstrated the potential of satellite navigation systems to provide accurate position information. Most recently, to provide more complete coverage and greater accuracy, the Navstar Global Positioning System, or GPS, was developed.

Navstar (navigation system with time and ranging) was begun in 1978. Navstar is a satellite-based, worldwide navigation system developed by the U.S. Department of Defense to provide rapid, high-resolution determination of location anywhere on earth. The system relies upon the deployment and control of a network of satellites that continuously broadcast timing, identification, and locational signals under the direction of a master control station in Colorado Springs, Colorado.

Each satellite is equipped with four precise atomic clocks that provide timing signals. Each satellite orbits the earth in a near-circular path at an altitude of about 11,000 miles[7]. The $10 billion system is managed by the Air Force Systems Command Space Systems Division.

Recently, the 23rd Navstar satellite was successfully launched. When fully deployed, the satellite system will be comprised of 24 satellites[8]: 21 active satellites plus three spares maintained in orbit. Interim system operation is expected to commence in the summer of 1993. Full operational status will entail replacement of all current satellites with upgraded models, to begin in late 1994 or 1995[9].

Conceptually, Navstar is very simple. Subject to certain constraints, discussed later, GPS receivers are used to detect and carefully time the arrival of very high frequency, line-of-site radio signals from several satellites, and thereby infer the distance to multiple satellites of known position. GPS receivers must, in principle, "acquire" at least three satellites to determine unambiguously the receiver's location on the surface of the earth (latitude and longitude). In practice, the need to obtain data to synchronize satellite clocks requires that four satellites be acquired[10]. In GPS parlance, the four satellites are said to provide "pseudorange" data. If an additional satellite is acquired, the receiver's altitude above the surface of the earth can also be determined, a critical component for aircraft-based GPS applications and certain land-based applications.

Currently, the Navstar system provides 2-D navigation coverage (latitude and longitude) up to 24 hours per day and 3-D coverage (including altitude), about 21 hours per day[11]. The exact coverage depends on a variety of factors. As discussed later, land use of the system either in town or in rough terrain is often more limited than airborne or marine-based applications, due to loss of line of sight to one or more satellites.

The overall accuracy of GPS systems depends upon a variety of factors, prominently among them, the accuracy of pseudorange measurements from the selected satellites. This constraining parameter is often described in terms of "dilution of precision" (DOP). Overall precision is enhanced by combining observations from different sets of four satellites, when a receiver can acquire more than four of the eight that are potentially in view. DOP, in turn, translates to a spherical error probability (SOP), representing the radius of a sphere which defines the 50 percentile equal error probability. Neglecting the height coordinate, the analogous 2-dimensional error characteristic is the circular error probability. i.e. the radius within which the true horizontal position lies with 50% probability.

For military purposes, the accuracy of independent measurements of position is claimed to be 58 feet or better. However, for civilian uses of an individual GPS receiver, the accuracy has been deliberately limited by the Department of Defense to about 328 feet[12], in order to prevent illegitimate military uses. This deliberate "fuzzing" or "selective availability" is accomplished by encrypting one of the two signals broadcast by each satellite, the so-called "P-signal" or precision signal, and providing the code only to legitimate military

users. The P—signal affords to legitimate military users all the information that is needed to correct for ionospheric delay errors[13] and thereby achieve the full precision possible with the current system. All other users have access to only the unencrypted "C/A" (coarse acquisition) signal[14].

Very high resolution position measurements are often claimed for commercial GPS equipment. Typically, such accuracy in position measurement requires either a lengthy period of data collection (so that additional sets of four satellites can move into the line of site) or an independent measurement of position, e.g. using surveying techniques and a differential position measurement using two receivers. The former approach affords, for surveyors, a submillimeter level of accuracy; it is not practical, however, for vehicles. In the latter approach, termed differential GPS, one receiver remains at the known, fixed location and records or rebroadcasts (on another channel) the information received from several satellites. The second, or differential, receiver can be moved around nearby and use information it receives from the same satellites, together with the rebroadcast signal from the first GPS receiver, to filter out the error introduced by selective availability. Alternatively, post—processing of the data from both receiver locations can be performed to obtain accuracy in the submeter range[15]. In either case, differential GPS imposes the additional requirements of 1) a second, fixed—position GPS receiver whose position is known precisely in advance; 2) additional signal processing, which could be done as post—data collection processing; and 3) limited range between the two receivers. So—called "differential ready" GPS receivers offer the potential to provide measurement accuracy of 30 feet or less, even with selective availability activated[16].

The simplest GPS systems display as output the current latitude and longitude of the receiver but provide no computer—compatible output signals (a requirement for the current application of data are to be logged for easy retrieval and use later). However, GPS receivers are available with a wide range of additional features, including integral serial ports[17] and computer terminals that can be used to output data to printers or other computers. A recent survey of marine GPS equipment documented as many as 53 suppliers worldwide of GPS equipment[18]. Commercial GPS—based navigation systems have, since the availability of relatively inexpensive receivers, been targeted primarily at operators of pleasure boats. Most manufacturers advertise prices in the range from about $800 up to $8,400 for such units.

Typical features for GPS receivers targeted at marine vessel and aircraft navigators (probably the largest user groups to date aside from the military) include storage of course data both in advance of and during data collection; provision of course correction information; antenna and/or display separated from the receiver; and integral geographical information systems to provide map data that can be associated with the GPS receiver outputs. The simplest GPS receivers acquire satellites sequentially; more sophisticated systems, some costing as much as $55,000, offer multiple channels for simultaneous, parallel satellite reception and multiple antennae, allowing for measuring the phase difference of arriving radio signals. The latter capability is offered in at least one full-feature product, which claims

to provide vessel (or vehicle) heading, pitch and roll to an accuracy in the range of 0.07-0.23°rms, for 1-second updated data[19].

GPS systems are currently used in many land-based vehicles for purposes including individual vehicle navigation, fleet tracking, emergency response, and resource location. In Operation Desert Storm, for example, most terrestrial vehicles were equipped with GPS. Reportedly, every major car manufacturer is currently involved in the development of GPS-based navigation equipment for its vehicles[20]. Some 50,000 navigation systems are already in operation in Japan alone[21], and several Japanese car manufacturers are now demonstrating systems using digitized maps that display current position to driver. Toshiba offers, in Japan, a GPS-based real-time navigation and travel management system[22].

It is not known exactly how many different models of GPS receiver are available for use in land-based vehicles, but it is believed that many of the suppliers of GPS systems for marine use offer the same or similar systems for land vehicles. The cost of land-based units, like their marine counterparts, is largely a function of the features included. As discussed below, however, there are several important differences between marine-based and land-based units.

Land-based units are, in most cases, more likely to be subject to obstruction of line-of-sight to one or more satellites. This can occur near mountains, extreme terrain and tree cover in nonurban areas, and near highway overpasses, street canyons, overhead structures, large buildings and other potential obstructions common in urbanized areas. A recent comparative investigation[23] of the availability of GPS and LORAN coverage along the roads of southern British Columbia found "significantly reduced GPS coverage...due to the presence of mountains." (As discussed later, LORAN was also found to suffer from signal attenuations in the vicinity of rugged topography.) On one road, GPS coverage was reported to average only 24.5% of the theoretically available coverage, primarily due to "the presence of steep mountains on one side of the road." That analysis even allowed for gaps up to 10 seconds; if second-by-second coverage were required, statistics would be poorer. The authors attributed most loss of coverage to the effects of topography and trees. They estimate that availability of the full Navstar satellite system "...would improve coverage significantly, without however, reaching the 100% mark in all cases."

In order to allow for temporary losses of satellite fix, many GPS-based vehicle navigation systems are actually hybrid systems, comprised of GPS receivers which provide absolute but somewhat intermittent locations fixes, and inertial or compass-based systems which provide dead reckoning of change of location during the times between satellite fixes. (Dead-reckoning systems and other elements of vehicle navigation systems are described in later sections of this report.)

The U.S. Coast Guard is currently in the process of installing differential GPS beacons, primarily as an aid to marine navigation[24]. To date, the west coast is not covered. However, at least one commercial service, Magnavox Electronic Systems[25] in conjunction with CUE Network Corporation, provides, for a fee, differential GPS beacons

for use with a GPS engine and a specialized FM pager receiver in the Greater Los Angeles area, generally covering the Los Angeles Basin. Nowsco, another commercial firm in southern California[26] offers integrated vehicle locating systems that utilize differential GPS together with dead reckoning to fill in data gaps due to loss of satellite line-of-site.

GPS-based vehicle location systems are rapidly expanding into the market of fleet tracking systems. Such systems afford the capability of tracking or locating vehicles quickly at any time. The Los Angeles Metropolitan Transportation Authority reportedly is planning to use GPS systems in order to track its vehicles[27]. Trimble Navigation produces a sophisticated GPS-based system called FleetVision, which is already in use by fleet managers in several cities[28]. For urban areas where GPS can be periodically screened from satellite line-of-site or where signal reflections can introduce system errors, Trimble offers a unit that includes supplemental dead reckoning navigation. Based on communications with several users of GPS systems in Los Angeles, such a supplemental system would likely be needed in order to avoid data gaps when using GPS in downtown areas with tall buildings[29,30]

LORAN

"LORAN," which stands for LOng RAnge Navigation, was one of the earliest practical radio-based navigation systems. Developed during World War II at a cost of about five million dollars[31], it is still in widespread use today. LORAN is primarily used for, but not limited to, marine navigation. As discussed later, land-use of LORAN is subject to additional constraints.

LORAN-C is a low frequency, hyperbolic radionavigation system. The U.S. Department of Transportation has designated LORAN-C as the government provided radionavigation system for the Coastal Confluence Zone[32]. LORAN-C operates using a stationary network of radio transmitters that broadcast a series of radio pulses at carefully timed intervals. By comparing the arrival times of signals from two nearby transmitters, a master transmitter and a secondary transmitter of a particular chain[33], a mobile radio receiver can obtain a "line of position" (LOP).[34] The crossing point of two or more LOPs, where each LOP is derived using the same master transmitter but a different secondary transmitter, fixes the receiver latitude and longitude. This series of steps may be followed and the position determined, without charts, by the use of automatic coordinate converters.

While LORAN continues to provide reliable navigation information for thousands of users, it has limitations. Under certain conditions, availability is limited[35] and accuracy can deteriorate badly[36]. In addition, the use of LORAN for land-based navigation is subject to several particular forms of land-based radio interference. For these and other reasons, the U.S. Government's General Accounting Office suggested, in the late 1980s, that GPS should be fully investigated as a possible alternative to then-contemplated upgrades to LORAN by the U.S. Coast Guard. However, GPS is still viewed by many as an experimental system and LORAN is expected to persist into the next century[37].

In a recent investigation[38] in British Columbia, LORAN-C and GPS were assessed for vehicular navigation along selected routes in a mountainous area. Along many road sections, LORAN-C was found to be available over 95% of the time. In other cases, availability was reduced, likely due to topography. Overall, these investigators found that LORAN-C signal availability was higher than that of GPS. Such comparative studies should be viewed with caution however, since results may vary depending upon specific local conditions, such as proximity to LORAN transmitters, visibility and selective availability of Navstar satellites, as well as other factors such as the type of receivers used.

In recent years, several surveys have been conducted on the sources and nature of anthropogenic radio frequency interference (RFI) that would be encountered by a land-based LORAN-C receiver in Los Angeles. An earlier survey by Teledyne found relatively poor LORAN-C signals in the Los Angeles area. A later study by Systems Control Inc. (SCI)[39] used an instrumented van to measure LORAN-C RFI in both urban and suburban locations and along freeways. SCI's measurements indicated that the principal types of RFI that may limit the performance of LORAN-C receivers in urban and suburban areas of Los Angeles were impulsive noise (mainly from nearby electric utility lines) and power line carrier communications. Other types of RFI documented by SCI but determined to be less significant were localized continuous wave signals, low-level signals, ignition noise and conventional power line noise. Severe impulse noise was found to exist in several locations.

As part of its investigation, SCI examined LORAN-C signal reception during travel between fixed measurement sites. SCI reported[40]:

> Generally, reception was quite good along open and elevated freeways. Occasional brief periods of noise would be encountered as the measurement van traveled by or under electric utility distribution lines containing impulsive noise. Signal fades were noticeable as the measurement van traveled under an overpass or a large overhead roadway sign.

SCI also reported instances of RFI from nearby vehicles, particularly in one case of a truck moving in a parallel lane of traffic.

SCI concluded as a result of its investigation that:

> Vehicular LORAN-C receivers moving along the streets and highways of Los Angeles would be subjected to a wide variety of radio environments. At times, low natural noise levels would result in excellent LORAN-C receiver performance. The extremely rapid transition from low level natural noise conditions to very high levels of impulsive noise, or very high levels of CW RFI, or combinations of the two states, must be carefully considered by the designers of vehicular LORAN-C receivers.

Unlike the case with GPS, our investigation found no widespread use of LORAN-C for land-based vehicles at the present time and no large-scale availability of commercial equipment designed for that purpose. For

these reasons and because of the constraints identified earlier, LORAN-based systems for land navigation in Los Angeles were not considered further.

Dead Reckoning

Dead reckoning or deduced reckoning, means "essentially nonobservational navigation by computations of position based on course and distance traveled from a known position[41]." In the context of land-based vehicle navigation, dead reckoning uses speed, time and compass direction to compute continuously the vehicle's estimated location with respect to a known starting location. Unlike dead reckoning systems for marine vessels and aircraft, land-based navigation by dead reckoning offers a convenient and accurate measurement of distance traveled, namely the odometer reading from start of trip. However, imprecision in the measurement of constantly changing headings is a major problem for land navigation by dead reckoning over long distances. For this reason, dead reckoning is most often used as a part of a hybrid navigation system that provides for minor corrections of position, either manually or automatically, during the course of a trip.

The Blaupunkt Travelpilot by Robert Bosch[42], is one example of a dead-reckoning-based land vehicle navigation system that is currently offered for sale ($2,495) in the U.S. and Europe[43]. Travelpilot, like all dead reckoning navigation, requires a manual input of starting position. It uses a magnetic flux gate (electronic) compass and dual wheel sensors to monitor position which is frequently updated by an on-board computer. The computer uses a series of algorithms to determine likely vehicle location based on last known location and incremental change in location. In addition, the computer algorithms refer at frequent intervals to a digital compact disc based road map to correct for relatively minor but frequent errors in position change that, if allowed to accumulate, would result in significant position errors. If the position calculated by dead reckoning places the vehicle to one side of a known roadway, an adjustment is made based on the assumption that the vehicle is on the nearest roadway. Notwithstanding these frequent automatic course corrections, Travelpilot, like other systems, does provide for operator intervention to correct position determinations when at a known location.

Other vehicle navigation systems that rely, in part, on dead reckoning also provide secondary means for determining or correcting absolute position. The prototype Motorola In-Vehicle Navigation System reportedly uses GPS to enhance the accuracy of the vehicle's system[44]. Germany's Siemens Automotive Ali-Scout vehicle navigation system communicates with infrared beacons mounted on traffic lights, using a flux gate compass and odometer readings in between. Nissan has recently introduced its third-generation vehicle navigation system which uses an optical fiber gyroscope to accurately sense the direction of vehicle motion. Optical fiber gyroscopes measure the change in rate of rotation of an optical fiber loop based on the Sagnac effect, which can be measured using solid-state laser interferometry[45], i.e. no moving parts and relative insensitivity to vibration. The other major advantages of

optical fiber gyroscopes over conventional mechanical ones are higher sensitivity and inherent static stability[46].

In addition to certain production systems in Japan and elsewhere, vehicle navigation systems that are integrated with intelligent vehicle highway systems are currently being tested or demonstrated in several areas[47]. Travtek, in Orlando, Florida, uses computerized dead reckoning together with Magnavox[48] GPS systems for navigation in 100 cars. Pathfinder in Los Angeles, which was co-sponsored by CALTRANS and other public and private entities, used dead reckoning in 25 vehicles that were also equipped with ETAC's "Travel Pilot" CD ROM (compact disc, read only memory) systems. Travel Pilot is, in some respects, a true dead reckoning system.

Travel Pilot stores detailed road maps of Los Angeles (maps are also available from ETAC for other cities). As Pathfinder vehicles navigated the roadway network, dead reckoning sensor input was provided by wheel rotation sensors and an onboard magnetic flux gate compass. These sensors provided the data needed to calculate approximate changes in position. Current position was successively updated with change in position, which was then constrained to the roadway system by an on-board navigation position-correction computer. The result was a system which, when properly calibrated, was reportedly easy to use and required little operator intervention[49]. The Pathfinder demonstration program has now been completed and some of the on-board equipment may be available in surplus[50].

Other Radio-Navigation Systems, Teletrac

Subsequent to the development and implementation of LORAN, advances in digital electronics have made possible the operation of sophisticated land-based radio-locating systems for vehicles. Such systems rely on the timing of high frequency radio transmissions between a mobile unit and fixed, ground-based radio towers. Teletrac is one example of such a system which services the greater Los Angeles area[51]. Because of the potential usefulness of Teletrac, it will be the sole subject of this section.

Teletrac is operated by Pacific Telesis and is a major provider of vehicle locating services in the Los Angeles area. Teletrac works by using a network of about 40 transmitting and receiving stations in Los Angeles to triangulate the position of a radio transponder installed in the vehicle (Teletrac calls this procedure "trilateration"). Upon request from a user, which may be sent from a local computer terminal, the Teletrac transmitters broadcast a signal that is received in the vehicle and activates the vehicle's transmitter. A brief timing broadcast sent from the transponder in the vehicle is received by two or more Teletrac receivers and the position is triangulated. Position information can be obtained by remote terminal from Teletrac's central computer. Information is available both as latitude/longitude and as street location shown on a map. The whole process, according to Teletrac, requires about 5-8 seconds and can be repeated at that frequency if desired. According to Teletrac, the accuracy of position determinations is about 150 feet.

Use of Teletrac requires installation of a radio transponder and antenna in the vehicle (about $575), a computer with modem (approximately $2000, unless equipment is already available), Teletrac software ($2000) and a service agreement. Teletrac functions as a pay-per-use service. The fee is currently $0.03 per location fix or a minimum charge of $10/month (includes 100 location fixes). Assuming a suitable computer and modem are already available, and that the test vehicle would be located by Teletrac every 10 seconds for two hours per day, eight days per month, the initial cost for Teletrac would be $2575 and the annual fee would be $2,074.

The Los Angeles County Metropolitan Transportation Authority (MTA) has used Teletrac for its Freeway Service Patrol System for more than two years. Currently, MTA is switching from Teletrac to a GPS-based system because of the lower per-unit cost of the latter (MTA operates hundreds of vehicles in its fleets and needs second-by-second data), limited coverage in certain areas[52], and queuing difficulties observed when, in stress tests conducted by MTA, more than 150 vehicles were polled simultaneously for position information.

Teletrac, like other vehicle locating systems, is undergoing improvements and changes as the technology matures and new technologies become available. One of Teletrac's current options, for an additional $150, is a status message terminal (SMT). This is a hardware system that attaches to the Teletrac transponder in the vehicle and allows the driver to enter any of thirteen codes at a data entry terminal for transmission to the Teletrac central computer[53]. Based on discussions with Teletrac technical staff, Sierra believes that Teletrac's SMT could probably be adapted to transmit fault codes recorded in the Lumina's on-board computer, which would be a secondary benefit of the system. A map of Teletrac's Los Angeles service area is provided in Figure 1.

While Teletrac offers some unique advantages over GPS, it also has several distinct disadvantages. First, being a pay-per-use system, it would be relatively expensive if used to a significant degree. Secondly, it was reported by one user that Teletrac, like GPS, can lose its fix in areas of high-rise buildings or steep terrain, due to loss of radio line-of-site and to signal reflections. For GPS systems supplemented with dead reckoning, such intermittent losses may not present a serious problem. However, Teletrac does not currently offer this feature. On the other hand, Teletrac provides not only latitude and longitude but also street location, which is an extremely valuable adjunct to basic position information and which would probably be required for any system if type of roadway is to be determined. Finally, Teletrac's advertised coverage of greater Los Angeles is quite good, but it obviously cannot match the potential worldwide coverage of GPS.

Figure 1

Teletrac Service Area
Southern California
LOS ANGELES COUNTY
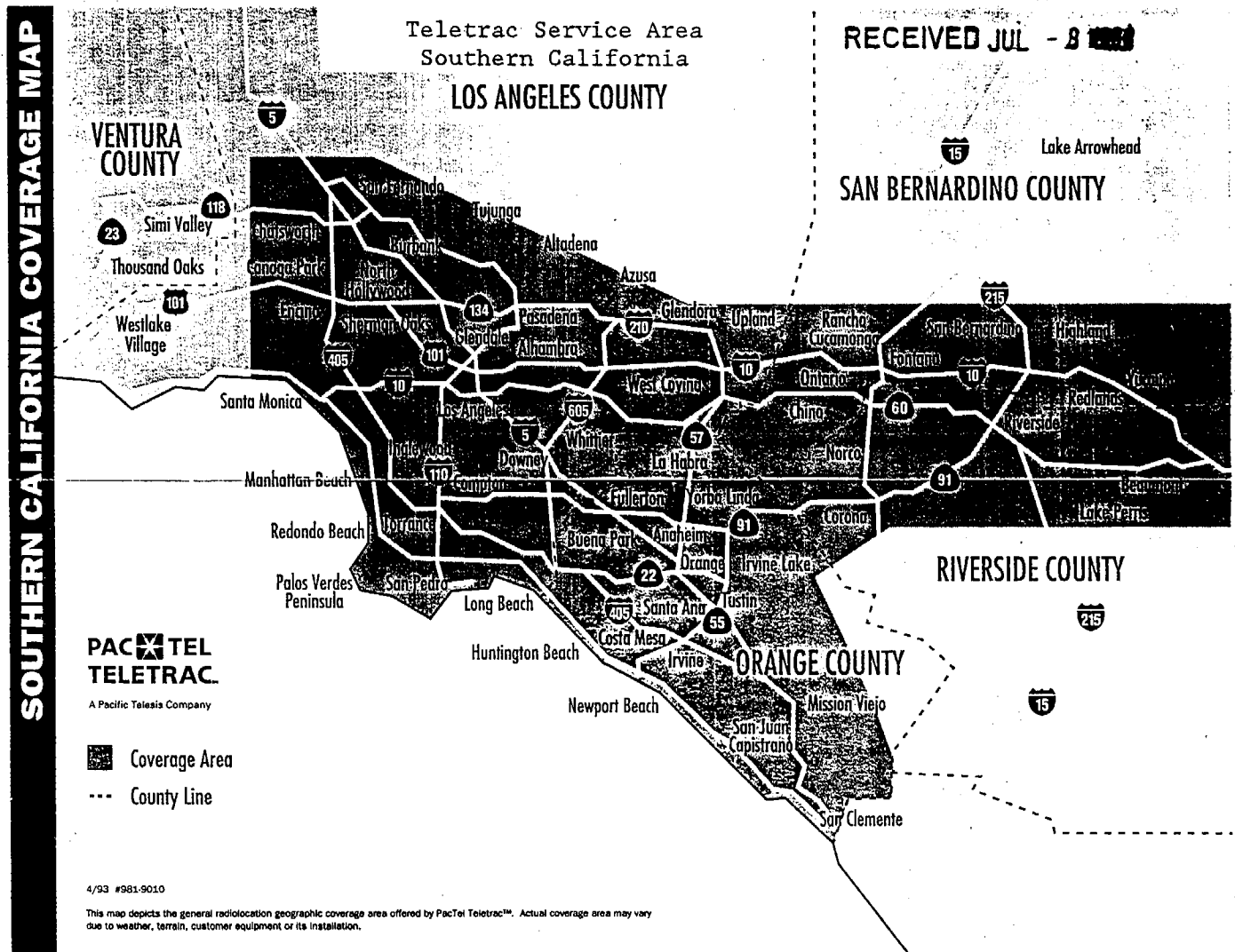
Conclusions and Recommendations

Based on the survey of currently available systems for vehicle location in Los Angeles, the following conclusions were reached. It should be noted that these conclusions pertain only to the application of vehicle locating systems to one specific test vehicle in Los Angeles and should not be construed otherwise.

1) Potentially, any or all of the types of systems that were examined could be used to provide some degree of capability for vehicle location in most of the greater Los Angeles area. However, LORAN-based commercial systems, which are primarily targeted at the marine navigator, are subject to radio interference on land, and dead reckoning based systems suffer from loss of accuracy over time. As a result, the principal competing systems, in terms of coverage, reliability, accuracy and cost, were GPS-based systems and Teletrac.

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2) To provide street names and locations, most GPS—based systems would have to be supplemented with a geographical information system that translates latitude/longitude pairs (the common output of a GPS system) with street names and locations. Teletrac provides both.

3) GPS—based systems that include dead reckoning to compensate for transmission losses are expected to have higher initial cost than Teletrac. However, GPS has no service fees or charges associated with frequent use, and very frequent position updates, as often as once per second, are possible. As a matter of practicality and cost, Teletrac position updates are only available about once every ten seconds.

4) Accuracy is comparable for both systems unless differential GPS is used (at a higher cost) or selective availability is turned off. In either of these cases, GPS offers somewhat greater position accuracy than Teletrac.

5) Vehicle location systems are in a rapidly changing state with new products, options and business arrangements being offered constantly and older, but apparently quite functional, equipment becoming available, sometimes from government agencies.

In consideration of the information obtained and the conclusions reached, the following is recommended:

1) In order to further define its needs and test the capabilities of a commercial vehicle location system, Sierra recommends that ARB arrange to use Teletrac, on a trial basis if possible, perhaps using surplus or spare transponder equipment.

2) In order to ensure that the optimum system is obtained, concurrent with its trial of Teletrac, ARB may want to continue exploring the potential for obtaining alternative systems either as demonstrations by vendors or as a result of functional systems that may be in surplus.

3) If ARB's needs for a vehicle locating system are fully met by Teletrac, ARB may wish to explore the use of a future version of Teletrac's status message terminal as a means of obtaining fault codes from the vehicle's on—board electronic control unit.

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